Magnetic Field Lines
Simulation of Iron Fillings around a Magnet

Time:
40 minutes

Objective:
Students will gain an understanding of the mechanics of magnetic field lines as demonstrated with iron fillings and a magnet and through a simulation model.

Teacher note
This is a simulation where the students can modify some of the parameters, but this is more of a demonstration and should be used in conjunction with lecture and hands on experiments. Advanced students are welcome to investigate the programming in the Starlogo models. They may modify the programs to make the simulation more real.

Content Standards:
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry
  - Use Technology and Mathematics to improve investigations and communications
  - Formulate and revise scientific explanations and models using logic and evidence
  - Recognize and analyze alternative explanations and models
- Physical Science – Content Standard B
  - Structure of atoms
  - Structure and properties of matter
  - Motions and forces
  - Conservation of energy and increase in disorder
  - Interactions of energy and matter

Equipment, Materials, and Tools:
- Computer – Mac or PC with Starlogo program from http://education.mit.edu/starlogo/
- StarLogo code file (magnet2.slogo) located in the Appendix section

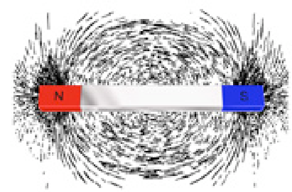
Background Information:
The ancient Greeks and the early Chinese knew about strange and rare stones with the power to attract iron. A steel needle stroked with such a "lodestone" became "magnetic" as well, and around 1000 AD the Chinese found that such a needle, when freely suspended, pointed north-south. A simple observation that lead to the beginning of the magnetic compass.

The magnetic compass soon spread to Europe. Columbus noted that the needle deviated slightly from exact north (as indicated by the stars) and that the deviation changed during the voyage. Around 1600 AD, William Gilbert proposed an explanation: the Earth itself was a giant magnet, with its magnetic poles some distance away from its geographic poles (i.e. near the points defining the Earth's axis).

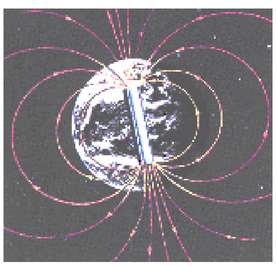
On Earth one only needs a sensitive needle to detect magnetic forces, but out in space they are usually much, much weaker. Beyond the Earth's dense atmosphere, such forces have a much larger role, and a region exists around the Earth where these forces dominate the environment, a region known as the Earth's magnetosphere. This region contains a mix of electrically charged particles, and electric and magnetic phenomena rather than gravity determine its structure.

Until 1821, magnetism produced by iron magnets was the only one known. Hans Christian Oersted, a Danish scientist, while demonstrating the flow of an electric current in a wire, noticed that the current caused a nearby compass needle to move. Andre-Marie Ampere in France studied this newly described phenomenon. He concluded that the nature of magnetism was quite different from what everyone had believed. It was basically a force between electric currents: two parallel currents in the same direction attract, in opposite directions they repel. Iron magnets are a very special case, which Ampere was also able to explain.

Michael Faraday, credited with fundamental discoveries on electricity and magnetism, also proposed a widely used method for visualizing magnetic fields. Imagine a compass needle freely suspended in three dimensions, near a magnet or an electrical current. We can trace in space the lines one obtains when one "follows the direction of the compass needle." Faraday called them lines of force, but the term field lines is now in common use.



Magnetic field lines describe magnetic fields. Magnetic field lines move in all directions but converge where the magnetic force is the strongest and spread out where it is weaker. When demonstrating magnetic field lines with a magnet and iron fillings, you can see that the magnetic force is the strongest at the ends of the magnet, the poles. Magnets are dipoles, having one pole at each end. The behavior of the Earth's magnetic field is similar to that of the magnet as the Earth acts as a dipole.



To Faraday, field lines were mainly a method of displaying the structure of the magnetic force. In space research, however, they have a much broader significance, because electrons and ions tend to stay attached to them, like beads on a wire, even becoming trapped when conditions are right. Because of this attachment, they define an "easy direction" in the rarefied gas of space, like the grain in a piece of wood, a direction in which ions and electrons, as well as electric currents can easily move.

Faraday not only viewed the space around a magnet as filled with field lines, but also developed an intuitive notion that such space was itself modified. James Maxwell, the great Scottish physicist, placed this notion on a firm mathematical footing, including in it electrical forces as well as magnetic ones. Such a modified space is now known as an electromagnetic field.

Today electromagnetic fields are a cornerstone of physics. Their basic equations, derived by Maxwell, suggested that they could undergo wave motion, spreading with the speed of light. Maxwell correctly guessed that this actually was light and that light was an electromagnetic wave.

Heinrich Hertz in Germany produced such waves by electrical means, in the first laboratory demonstration of radio waves. Today, a wide variety of such waves are known, from radio (very long waves) to microwaves, infra-red, visible light, ultra-violet, x-rays and gamma rays (very short waves).

Radio waves produced in our magnetosphere are often modified by their environment and tell us about the particles trapped there. Other such waves have been detected from the magnetospheres of distant planets, the Sun and the distant universe. X-rays, too, are observed to come from such sources and are the signatures of high-energy electrons there.

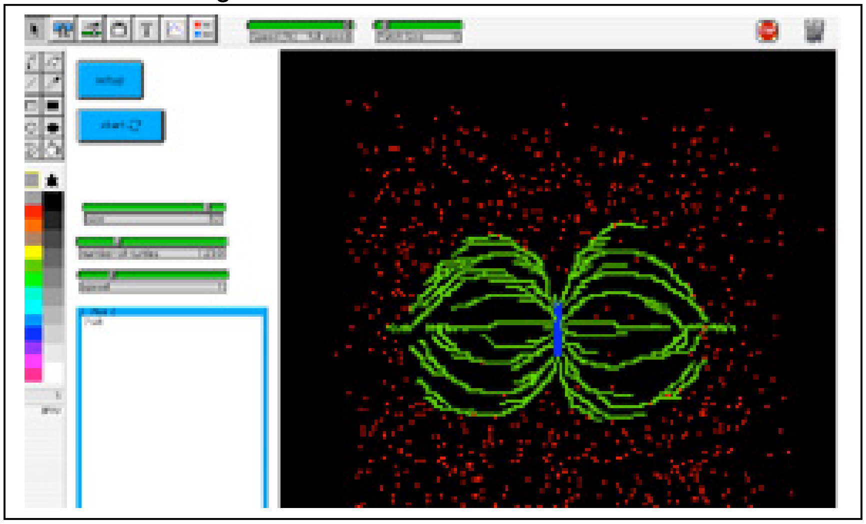
Only a few of the phenomena observed on the ground come from the magnetosphere: fluctuations of the magnetic field known as magnetic storms and sub-storms, and the polar aurora or "northern lights," appearing in the night skies of places like Alaska and Norway. Satellites in space, however, sense much more: radiation belts, magnetic structures, fast streaming particles and processes that energize them.

In space, magnetic field lines are fundamental to the way free electrons and ions move. These charged particles become attached to field lines and spiral around them while they slide along them. The behavior of plasma, electrified gas of free ions and electrons, is dictated by field lines in space. Electric currents find it easiest to flow along such lines. It is along the field lines which particles, electric currents, heat and certain types of waves prefer to flow.

Instructions:

1. Download and install StarLogo software from http://education.mit.edu/starlogo/ on your computer.
2. Start StarLogo. Select File, Open Project and select “magnet2.slogo” (you must copy the program code from the Appendix and save as “magnet2.slogo.” From the “Windows” select tool, select “Interface.” You should see the following screen:

This activity simulates the the alignment of particles (the red dots) along lines of magnetic force (the green lines). As the particles align you see them disappear. Notice the movement toward the stronger polar regions.



This computer simulation will help demonstrate the mechanics in how iron fillings represent the magnetic field lines. Often the dropping of iron fillings on a plastic sheet or piece of paper gets very messy and sometimes does not even show exactly what you want because of things like the magnet being too weak or strong.

NOTES FOR TEACHER This is a simulation where students can modify some of the parameters, but this is more of a demonstration and should be used in conjunction with lecture and hands on experiments.

Place a bar magnet on a table. Place a piece of paper over the bar magnet. Spread iron fillings on the paper and have the students observe what happens to the fillings. Have students sketch the shapes observed.